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Physics Procedia 42 (2013) 99 – 105
Physics Procedia

PNCMI 2012 - Polarized Neutrons for Condensed Matter Investigations 2012

Ultra-Sensitive Depolarization Study of Polarizing CoTi Supermirrors With The Opaque Test Bench

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Abstract

We have investigated the depolarization of neutrons in the reflection on polarizing supermirrors, using the opaque test bench. It consists of two opaque ^{3}He cells with in-situ adiabatic fast passage flipping of the helium spin. In a beam initially polarized to AP=99.98 %, depolarization of the order of 10^{-2} is evidenced after a single reflection on a polarizing supermirror. Depolarization could be reduced though not completely suppressed when working at high magnetizing fields (0.82 T). The preliminary data analysis also suggests a correlation between the m-value of the supermirror and depolarization.

Selection and peer-review under responsibility of the Organizing Committee of the 9th International Workshop on Polarised Neutrons in Condensed Matter Investigations

Keywords: polarizing supermirrors, neutron polarization, neutron beta decay

1. Introduction

Polarizing supermirrors are widely used to polarize neutrons. They are based on the principle that the scattering length in ferromagnets depends on the neutron spin orientation leading to different critical angles for the two spin orientations. Hence, one orientation can be reflected while the other gets transmitted. The angular range of this polarizing effect can be enhanced when combining with the supermirror technique: Multiple layers of varying thicknesses alternating between a ferromagnetic material and a neutral one, having a Fermi pseudo-potential at the same level as the lower spin state in the ferromagnet, allow for constructive Bragg interferences for various wavelengths [1]. Supermirrors are well suited to polarize large, divergent, cold neutron beams as used in neutron β-decay precision measurements [2, 3]: Large beam cross sections can be easily covered and the polarization degree varies only slightly over the typical wavelength and divergence range. So far, the highest polarization of a cold, white neutron beam polarized by

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doi:10.1016/j.phpro.2013.03.181

supermirrors has been measured to be 99.7 % in neutron β-decay asymmetry measurements [4, 5, 6]. This is not sufficient for the next generation of β-decay instruments aiming at an accuracy of 10^{-4} [7]. It was achieved using the so called crossed geometry (X-SM geometry) [8]. In this geometry, two successive supermirror benders are used, with the second one turned by 90° with respect to the first one. The neutron spin is transported adiabatically between the corresponding magnetic field orientations. Through this procedure, the reflection angles in the successive benders are independent from each other, thus fully exploiting the available phase space. The independence of the reflection angles permits to calculate the polarization power of the set-up from the individual polarization powers of the two benders. However, the polarization degree measured for this set-up was far below expectations. This was attributed to a depolarization of the beam within the polarizer [8]. In a later measurement, depolarization in a polarizing supermirror bender has been directly measured by the Opaque Test Bench [9]: Depolarization of a beam polarized to more than 99.99% was measured to be several times 10^{-3} [9, 10]. In this paper, we present the first results from a systematic study on depolarizing effects in polarizing supermirrors using the Opaque Test Bench. The set-up will be presented in section 2. Results for the variation of different parameters such as the magnetizing field magnitude, number of layers as well as the incident angle and wavelength for CoTi mirrors are presented in section 3 and an overall conclusion is given in section 4. The supermirror factor m referred to in this work is taken with respect to the critical angle of nickel.

2. Experiment

In this experiment, depolarization produced by a single reflection on a supermirror sample was measured. The set-up, depicted in Fig. 1, is a very basic reflectometer combined with the Opaque Test Bench. The white, cold high flux beam of PF1B [11] gets reduced to a 5.3 Å (through a Dornier velocity selector, $\frac{\Delta\lambda}{\lambda} \sim 10\%$), 2mm wide beam. The beam is polarized by a first, highly opaque ^{3}He cell [12] with the opacity of $O = 8.1$ as defined in [13] and an initial helium polarization of $P_{\mathrm{He}} = 0.75$. These parameters result in the expected neutron polarization $P_{\mathrm{n}} = \tanh(O \cdot P_{\mathrm{He}}) = 99.999\%$ and transmission $T_{\mathrm{n}} = e^{-O} \cdot \cosh(O \cdot P_{\mathrm{He}}) = 6.6\%$. The beam then encounters the sample mirror and the reflected beam is analyzed by a second, similarly opaque ^{3}He cell. The He spin in the polarizer cell can be flipped via adiabatic fast passage flippers [14], resulting in the transmission of the opposite spin. This allows to precisely measure the depolarization due to the sample via the cells' combined Analyzing and Polarizing powers, AP. The sample is set in a magnetic field that can be varied from 0.02 to 0.82 tesla. Between the electromagnet and the He cells, guide fields assure an adiabatic spin transport. The moveable detector is set behind a slit, counting only neutrons from the reflection peak. Gd or LiF were used for neutron shielding to avoid a potential depolarization by magnetic residues usually present in B_4C rubber. The electromagnet's field was measured to be sufficiently homogeneous at the sample position. The neutron polarization was measured to be higher than AP=99.98% for the direct beam without sample.
We present data for samples with Co as a ferromagnetic material. The following samples were used: CoTi m=2 mirror, CoTi m=2.8 mirror, CoTi m=2.8 mirror with an absorbing Gd layer, Co monolayer 800Å thick, Co monolayer 2000 Å thick. FeSi mirrors have been looked at rapidly, but futher measurements are needed for an analysis. The samples, produced by the Neutron Optics Service of the ILL, were sputtered onto a 38 mm x 60 mm Si wafer. The supermirrors were generally studied at half of their critical angle, $\frac{\theta_c}{2}$. This

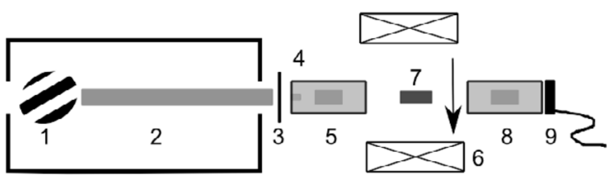

Fig. 1. A sketched side view of the set-up. A velocity selector (1) fixes the wavelength. The neutrons travel further via a neutron guide (2) and a shutter (3) to the polarizer cell (5). The sample (7) is inside the electromagnet (6). After the subsequent analyzing cell (8), the neutron gets detected (9).

guarantees almost complete suppression of the spin down component and high reflectivity for the up component. The Co monolayers are placed at about 80 % of the critical angle to obtain sufficient separation of the reflected and transmitted beams. Measurement of one data point takes about 0.5 hours for a statistical precision well below 10^{-4}, compared with cells' lifetimes T_1 longer than 140 hours. Freshly polarized cells were installed at least every 24 hours.

3. Result

3.1. Magnetizing Field

During the measurement, the samples were subject to a variety of magnetizing fields. At B=0.04 tesla, a typical value for the field in polarizing benders, depolarization is observed for all the samples and ranges from a few times 10^{-4} to several percents. As reported in Fig. 2, depolarization does get reduced for higher field strengths. At the maximal field of 0.82 T, depolarization still remains, though to a much smaller extent than initially. This behaviour is consistent with inhomogeneous orientations of magnetic domains in the supermirror.

3.2. Scattering Angle, Wavelength and the Supermirror Factor m

For CoTi mirrors and Co monolayers, a systematic study has been performed. The results are summarized in Figures 3-6.
As can also be seen from Fig. 2 and shown again in Fig. 3, the m=2.0 mirror depolarizes to a lesser degree than the m=2.8 one. In addition, a 800 Å and a 2000Å thick Co layer (m=0.84) have a significantly lower depolarization than the supermirrors. Above 0.04 T, both monolayers behave similarily. The depolarization of the CoTi m=2.8 mirror with an absorbing Gd layer is similar to the one of a CoTi m=2.8 without this absorbing element.
While measurements in Fig. 3 were performed at roughly 50% of the respective critical angle, Fig. 4 shows the angular dependence in the case of an m=2.8 CoTi mirror (30%, 50% and 80% of θ_c). At low field, the depolarization varies with the reflection angles. Above 0.2 T though, the curves converge. In the course of the experiment, we observed that at low and very low field, in general, results in depolarization vary strongly even for the same sample configuration, possibly due to hysteresis-like effects being more visible at low field.
Similarly, in Fig. 5 a m=2.8 and a m=2.0 mirror were compared in terms of depolarization at 5.3 Å and 7.96 Å at the fixed incidence angle corresponding to 50% of the critical angle at 5.3 Å. The longer wavelength depolarizes slightly more for both supermirror factors. Above 0.3 T, the respective curves come together and at the maximum field of 0.8 T there is no significant deviation anymore.
The angular study is completed by looking at the m=2.0 and the m=2.8 mirror, both set to the same incidence angle of 19 mrad, reported in Fig. 6. Again, depolarization is more prominent for the higher supermirror factor.

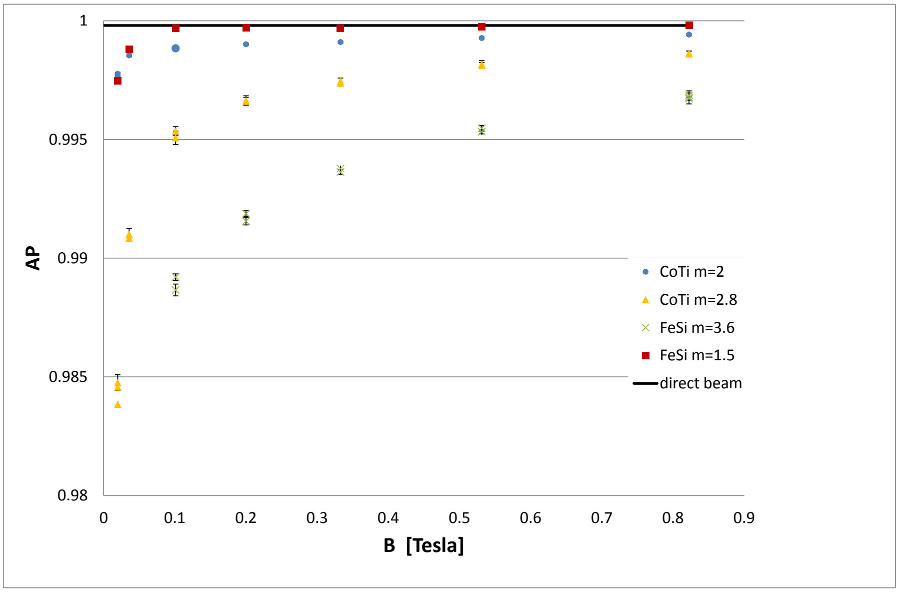

Fig. 2. Depolarization at 5.3 Å for a variety of supermirrors, all measured at half of their respective critical angle.

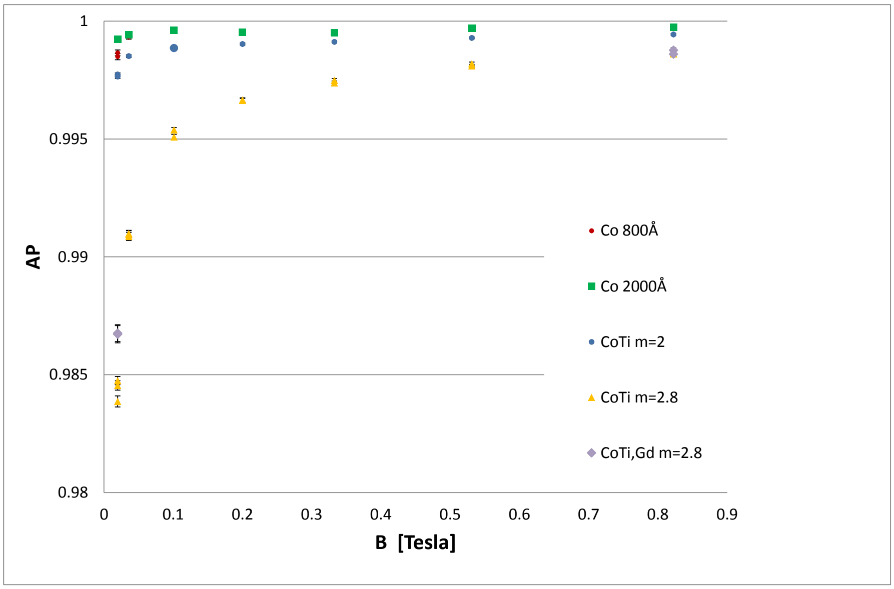

Fig. 3. Depolarization at 5.3 Å for m=2.0 and m=2.8 CoTi supermirrors at 50% of their respective critical angles and for Co monolayers at 80% of its critical angle.

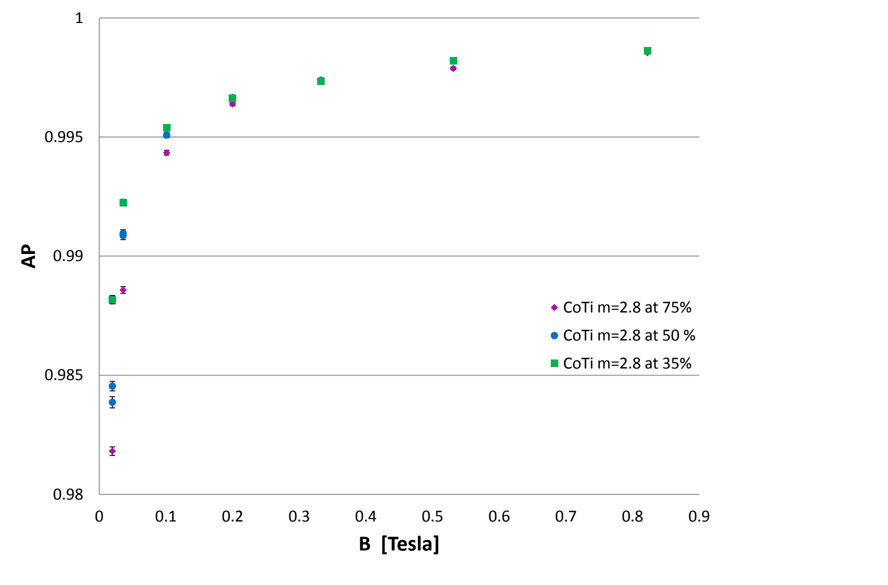

Fig. 4. Depolarization at 5.3 Å for a CoTi m=2.8 supermirror at 35%, 50% and 80 % of its critical angle.

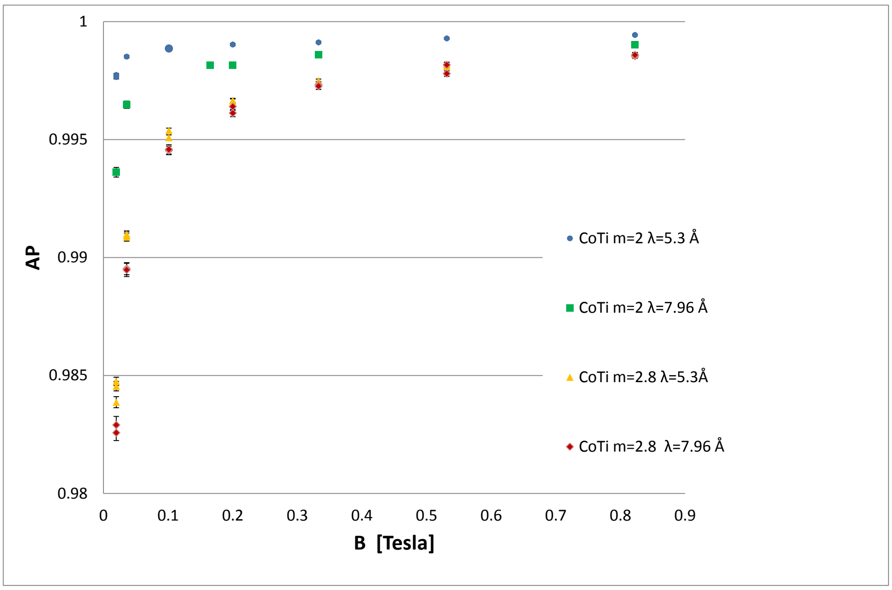

Fig. 5. Depolarization at 5.3 Å and 7.96 Å for two CoTi supermirrors of m=2 and m=2.8 measured at 50 % of their respective critical angle.

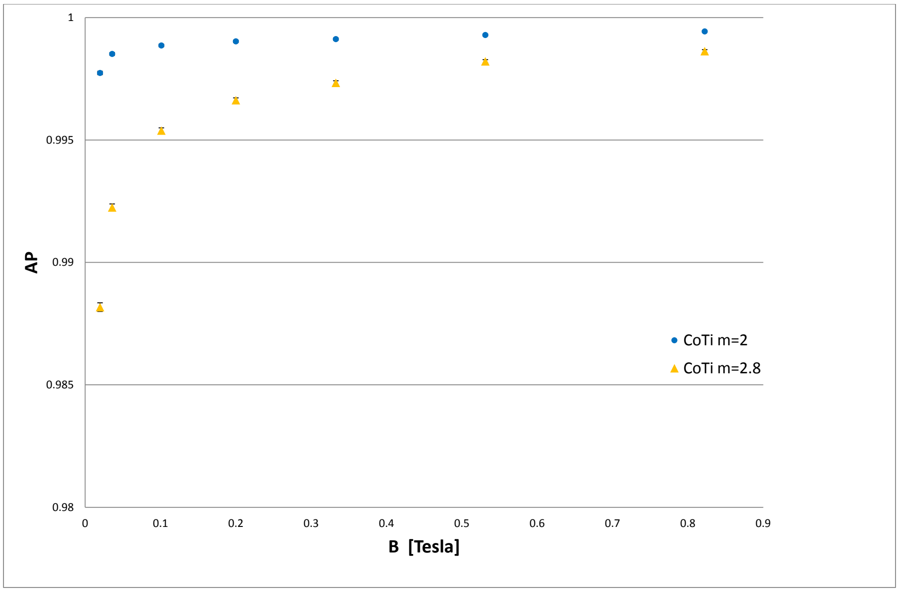

Fig. 6. Depolarization at 5.3 Å for two CoTi supermirrors of m=2 and m=2.8 at the same incidence angle of 19 mrad.

4. Conclusion

Depolarization in polarizing supermirrors is an issue when requiring ultra high neutron polarization. We have studied this depolarization for different samples using the Opaque Test Bench as a highly precise measuring device. The presented data on CoTi supermirrors indicate higher depolarization for higher supermirror factors. Depolarization can be reduced by high magnetizing field in the order of 1 T. Supplementary beamtime has been allocated to complement the current studies with comprehensive data on FeSi supermirrors. First data indicate a different behaviour from CoTi. Additionally, depolarization not only in reflection, but also in transmission is to be studied. These depolarization studies are to be complemented with hysteresis curve measurements as well as possible off-specular scattering experiments [15]. Note that off-specular experiments can be carried out with much lower accuracy due to the lower contribution of these neutrons to the total intensity transmitted by a super mirror polariser.

5. Acknowledgement

This work was supported by the priority program "Precision experiments in particle-and astrophysics with cold and ultra cold neutrons" (SPP1491, grant SO 1058/1-1) of the Deutsche Forschungsgemeinschaft.

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